Naval Surface Warfare Center
Carderock Division
West Bethesda, MD 20817-5700

NSWCCD-65-TR–2004/37 January 2005

Survivability, Structures, and Materials Department

Technical Report

SIDER Testing of Impact Damaged Sandwich Panels

by

Roger M. Crane
NSWC, Carderock Division

Colin P. Ratcliffe
United States Naval Academy

Approved for public release; distribution is unlimited.

DEPARTMENT OF THE NAVY
NAVAL SURFACE WARFARE CENTER, CARDEROCK DIVISION
9500 MACARTHUR BOULEVARD
WEST BETHESDA MD 20817-5700

9078
Ser 65/11-84
5 Jul 11

From: Commander, Naval Surface Warfare Center, Carderock Division
To: Chief of Naval Research (ONR 332)

Subj: SIDER INSPECTIONS OF FOUR COMPOSITE SANDWICH PANELS

Ref: (a) Seaborne Structures Materials Program, Program Element 0602123N

Encl: (1) NSWCCD-65-TR–2004/37, *SIDER Testing of Impact Damaged Sandwich Panels*

1. Reference (a) requested the Naval Surface Warfare Center, Carderock Division (NSWCCD) to investigate the use of broadband vibration data to determine the integrity of composite structures. Enclosure (1) describes the use of the Structural Integrity and Damage Evaluation Routine (SIDER) to locate areas of structural irregularities for each of the four panels of different construction.

2. Comments or questions may be referred to Dr. Roger M. Crane, Code 655; telephone (301) 227-5126; e-mail, Roger.Crane@navy.mil.

E. A. RASMUSSEN
By direction

Subj: SIDER INSPECTIONS OF FOUR COMPOSITE SANDWICH PANELS

Copy to:

CNR ARLINGTON VA [ONR 331 (Barsoum), ONR 332 (Perez, Rajapakse)]

COMNAVSEASYSCOM WASHINGTON DC [SEA 05P2 (Green, Owen), SEA 05P4 (Nappi)]

USNA ANNAPOLIS MD [Mechanical Engineering Department (Dr. Colin P. Ratcliffe)]

COMNAVAIRSYSCOM PATUXENT RIVER MD [Code 4.3.4.4 (Meilunas)]

DTIC FORT BELVOIR VA

NAVSURFWARCEN CARDEROCKDIV BETHESDA MD [Codes 0112 (Barkyoumb), 3850 (TIC), 5080 (Dozier), 60 (Sharepoint), 603 (Price), 61, 611 (Bandos, Collins, Deloach), 6501 (Telegadas), 651(Bartlett), 652, 655, 655 (Crane, Coffin, B. Jones, Nguyen, Stager)]

Attn: Dr. Kevin Koudela, Dr. Tom Juska
Applied Research Laboratory
Pennsylvania State University
P.O. Box 30
State College, PA 16804

Attn: Dr. John W. Gillespie, Jr.
Director, CCM
Composites Manufacturing Science Laboratory
University of Delaware
Newark, DE 19716

Naval Surface Warfare Center
Carderock Division
West Bethesda, MD 20817-5700

NSWCCD-65-TR–2004/37 January 2005

Survivability, Structures, and Materials Department

Technical Report

SIDER Testing of Impact Damaged Sandwich Panels

by

Roger M. Crane
NSWC, Carderock Division

Colin P. Ratcliffe
United States Naval Academy

Approved for public release; distribution is unlimited.

Enclosure (1)

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing this collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number. **PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.**

1. REPORT DATE *(DD-MM-YYYY)*	**2. REPORT TYPE**	**3. DATES COVERED** *(From - To)*
1-Jan-2005	Final	-

4. TITLE AND SUBTITLE

SIDER Testing of Impact Damaged Sandwich Panels

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

Roger M. Crane and Colin P. Ratcliffe

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) AND ADDRESS(ES)

Naval Surface Warfare Center
Carderock Division
9500 Macarthur Boulevard
West Bethesda, MD 20817-5700

8. PERFORMING ORGANIZATION REPORT NUMBER

NSWCCD-65-TR–2004/37

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Attn ONR 332
Chief of Naval Research
One Liberty Center
875 North Randolph St., Suite 1425
Arlington, VA 22203-1995

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

This report presents the results of applying the Structural Integrity and Damage Evaluation Routine (SIDER) testing technique to four large composite sandwich panels. Each of these panels is a sandwich core construction with E-glass facesheets. All of the facesheets were made using 24 oz. E-glass woven roving layed up in a warps parallel configuration to a thickness of 0.25 in. The results are for a single SIDER analysis of each panel, and therefore are indicative of stiffness variability in the panels. The SIDER testing successfully identified impact damage areas created from drop weight impact testing.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
					Dr. Roger M. Crane
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**			**19b. TELEPHONE NUMBER** *(include area code)*
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	SAR	31	(301)-227-5126

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39.18

Contents

Page

Contents iii
Tables v
Administrative Information vi
Acknowledgements vi
Introduction 1
Description 1
    Grid 2
    Accelerometer Locations 5
Data Quality 6
    Observations from the Average Coherence Results 9
Sider Test Results 9
Conclusions 21
References 21

Figures

Page

Figure 1. Test Mesh for: Foam core, 662-lb 1-ft (Li_1) and Foam Core, 662-lb 2-ft (Front (Li_2) and Backside Li_4) Tests) 3
Figure 2. Test Mesh for the Webcore 662-lb 3-ft Panel (Li_3) Backside Test 4
Figure 3. Test Mesh for the Undamaged Webcore Panel (Li_5) with End Fixtures 5
Figure 4. Average Coherence Comparison between Test Parts....6
Figure 5. Average Coherence by Accelerometer for Foam Core 662-lb 1-ft 7
Figure 6. Average Coherence by Accelerometer for Foam Core 662-lb 2-ft 7
Figure 7. Average Coherence by Accelerometer for Webcore 662-lb 3-ft Backside Test Average Coherence by Accelerometer for Webcore 662-lb 3-ft Backside Test 8
Figure 8. Average Coherence by Accelerometer for Foam Core 662-lb 2-ft Backside Test 8
Figure 9. Average Coherence by Accelerometer for Webcore Undamaged with End Fixtures 9
Figure 10. Foam 662-lb 1-ft (Li_1) X-Direction Analysis -Unweighted 11
Figure 11. Foam 662-lb 1-ft (Li_1) Y-Direction Analysis -Unweighted 11
Figure 12. Foam 662-lb 1-ft (Li_1) X-Direction Analysis -Pie-Plate Weighting....12
Figure 13. Foam 662-lb 1-ft (Li_1) Y-Direction Analysis -Pie-Plate Weighting....12
Figure 14. Foam 662-lb 2-ft (Li_2) X-Direction Analysis -Unweighted 13
Figure 15. Foam 662-lb 2-ft (Li_2) Y-Direction Analysis -Unweighted 13
Figure 16. Foam 662-lb 2-ft (Li_2) X-Direction Analysis -Pie-Plate Weighting....14
Figure 17. Foam 662-lb 2-ft (Li_2) Y-Direction Analysis -Pie-Plate Weighting....14
Figure 18. Webcore 662-lb 3-ft (Li_3) X-Direction Analysis – Unweighted – Backside Test 15
Figure 19. Webcore 662-lb 3-ft (Li_3) Y-Direction Analysis - Unweighted – Backside Test 15
Figure 20. Webcore 662-lb 3-ft (Li_3) X-Direction Analysis - Pie-Plate Weighting – Backside Test....16
Figure 21. Webcore 662-lb 3-ft (Li_3) y-Direction Analysis -Pie-Plate Weighting – Backside Test 16
Figure 22. Foam 662-lb 2-ft (Li_4) x-Direction Analysis – Unweighted – Backside Test 17
Figure 23. Foam 662-lb 2-ft (Li_4) Y-Direction Analysis – Unweighted – Backside Test 17
Figure 24. Foam 662-lb 2-ft (Li_4) x-Direction Analysis -Pie-Plate Weighting – Backside Test 18
Figure 25. Foam 662-lb 2-ft (Li_4) y-Direction Analysis -Pie-Plate Weighting – Backside Test 18
Figure 26. Webcore Undamaged (Li_5) x-Direction Analysis – Unweighted 10 × Magnification 19

Figures

Page

Figure 27. Webcore Undamaged (Li_5) y-Direction Analysis – Unweighted 10 × Magnification 19
Figure 28. Webcore Undamaged (Li_5) x-Direction Analysis -Pie-Plate Weighting 10 × Magnification 20
Figure 29. Webcore Undamaged (Li_5) y-Direction Analysis -Pie-Plate Weighting 10 × Magnification 20

Tables

Page

Table 1. Test Matrix.....1
Table 2. Location of the Accelerometers.....5

Administrative Information

The work described in this report was performed by the Structures and Composites Division (Code 65) of the Survivability, Structures and Materials Department at the Naval Surface Warfare Center, Carderock Division (NSWCCD). The work was funded by the Office of Naval Research, Dr. Ignacio Perez, ONR 332 as part of the Seaborne Structures Materials Program, Program Element 0602123N. It was an investigation of the Structural Integrity and Damage Evaluation Routine (SIDER) used to assess the impact damage in composite sandwich panels manufactured with various core materials.

Acknowledgements

The authors would like to acknowledge the financial support of the IR & IED Program, NSWC, Carderock Division for this testing. This effort was administered by Dr. Liming Salvino, Code 652.

Introduction

This report presents the results of Structural Integrity and Damage Evaluation Routine (SIDER) inspections performed on four composite sandwich panels manufactured for the ONR materials program. The panels included polyvinyl chloride (PVC) foam core and Webcore construction which had been manufactured for a previous program to investigate the effect of impact on residual compression strength. The testing reported here was performed to compare the SIDER technique to two other nondestructive inspection techniques. The results from those procedures are not presented here. The SIDER technique has previously been used to identify locations where there is variability in structural stiffness. These areas are either due to the variability of the structure itself, or are manufacturing defects, or are locations of in-service damage.

The primary focus of the effort reported here was to use the SIDER technique to locate areas of structural irregularities for each of the four panels of different construction that were subjected to varying impact energies. This report archives the results, so that later they can be compared to the inspection results obtained from alternative inspection techniques being developed at NSWC, Carderock Division and NRL once those results are available. The details of the SIDER test procedure are not reported here but are available in References 1 and 2. The effort is focused on demonstrating that a rapid examination can be used to determine structural variability.

Description

The parts that were inspected were each nominally 4 feet by 3 feet and 1 inch thick. Two of the panels had a foam core and had been impact tested. Two panels were of Webcore Technologies, Inc. Tycore construction, one of which was impact tested and one was nominally undamaged. The undamaged panel had steel end fixtures in preparation for end load compression testing. Table 1 is a summary of the test articles and transducer locations.

Table 1. Test Matrix

Test Designator	Description	Test
Li_1	Foam core after 662-lb 1-ft impact test	Transducers and excitation on impacted side
Li_2	Foam core after 662-lb 2-ft impact test	Transducers and excitation on impacted side
Li_3	Webcore after 662-lb 3-ft impact test	Transducers and excitation on non-impacted side
Li_4	Foam core after 662-lb 2-ft impact test (same panel as test Li_2)	Transducers and excitation on non- impacted side
Li_5	Webcore with steel end fixtures. No impact testing, so nominally undamaged	Transducers and excitation on same surface

The parts were inspected at the Naval Surface Warfare Center, Carderock Division, on May 5-6, 2004. To perform a SIDER inspection, normally a test grid is marked directly onto each structure to locate the excitation locations. For this multi-panel test, it was decided to try a new approach. The test mesh was first marked on a plastic sheet. This sheet was then laid on each panel in turn, and the structure was tested through the plastic sheet. The time taken to prepare the plastic sheet was about half an hour, being comparable to the time it normally takes to mark the mesh directly onto the structure. It only took a few minutes to transfer the sheet from one panel, and align it on the next sheet. Thus, there was an overall total time saving of about two hours for the five tests. Data capture took approximately 1 hour per panel, and initial data reduction an additional 30 minutes per panel.

In addition to the SIDER data, raw time data for impact and responses were also digitally recorded and passed onto one of the NSWC, Carderock Division research engineers for further analysis using an alternative technique. The sampling rate for SIDER (approximately 5120 samples per second) was not suitable for the raw time trial data which were requested. Therefore, the time response aspect was treated as a separate experiment using a sampling rate of 51.2×10^3 samples per second. The time data are not reported here, and were distributed electronically under separate cover.

Grid

In order to conduct a SIDER analysis, the structure needs to be marked with a mesh of test points. It was decided to use a uniform two-inch square mesh. This mesh size would be sufficiently fine to resolve the structural variability or anomalies of interest. In addition, the mesh size would enable mesh marking and complete data acquisition within a short time frame. The time it takes for data acquisition is approximately proportional to the number of test points. As described previously, the mesh was marked on a plastic sheet which was aligned and taped to each panel as it was tested.

The test meshes are shown in Figure 1 through Figure 3. The individual test points are the uniform mesh of numbered crosses. For this series of tests, four response accelerometers were used. Their locations are shown as symbols with the letters A, B, C and D. The origin for the test mesh was chosen as the “top-left” corner of each panel. The x-axis direction was in the direction of the 3-foot side (down), the y-axis was in the direction of the 4-foot side (right), and the z-direction was up (out of the page). The first test point was located at coordinate position (1, 1, 0) inches. Note that some of the panels were slightly smaller than the nominal size and therefore rows and columns of test points were dropped from the test mesh as necessary. Also, the undamaged Webcore panel had end fixtures that covered several test points. The test mesh for this panel was established using the same origin (corner of the panel), but several rows of test points had to be dropped from the test. The figures include the outside frame of the nominal size of the panels.

The first point was identified as point # ‘11’. The point numbers incremented along the x-axis direction, with the last point on the first row being point #28. The first point on the second row, at coordinate (1, 3, 0) inches, was point #31. The final test point was #488. Thus the mesh was 18×24, with 432 test points.

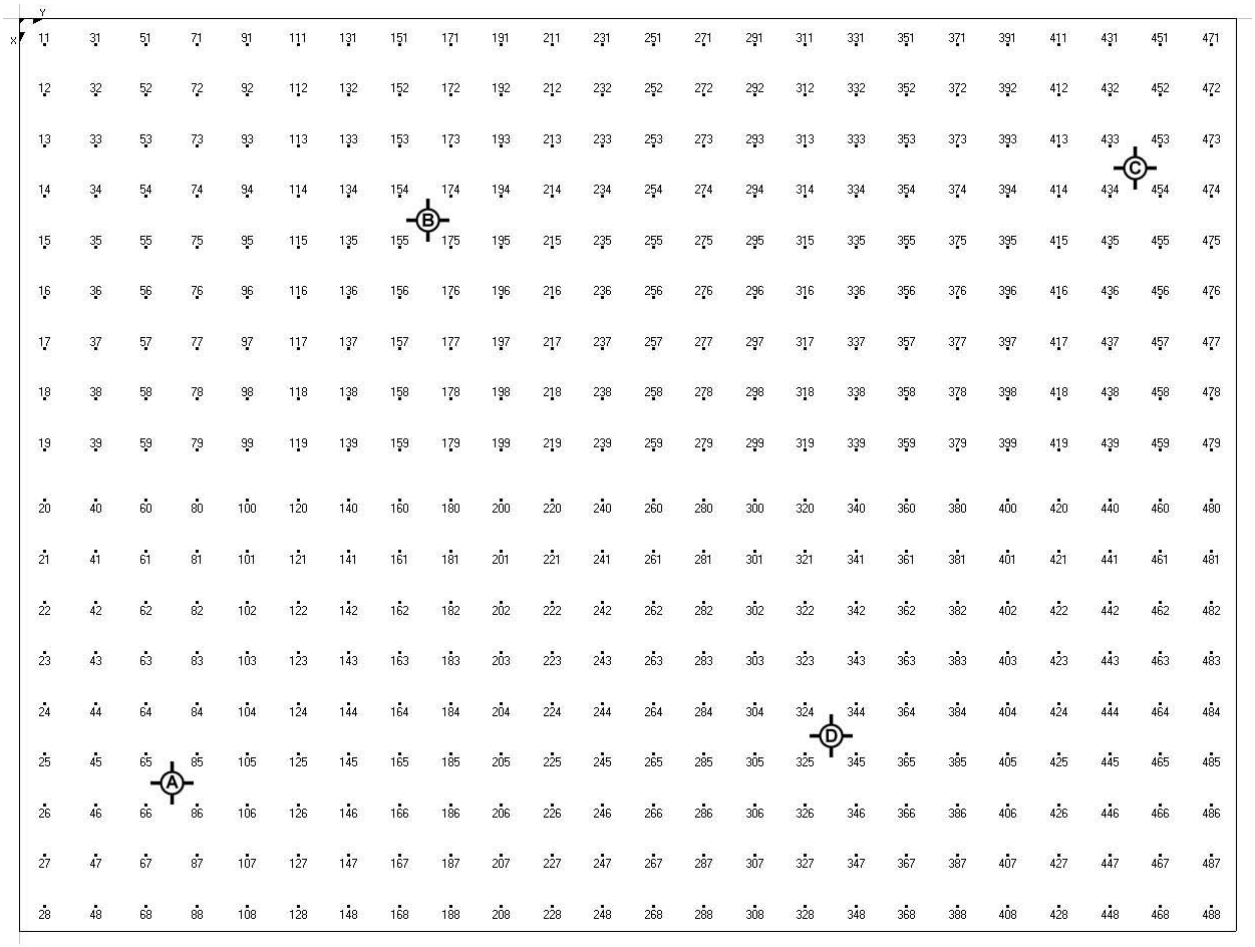

Figure 1. Test Mesh for: Foam core, 662-lb 1-ft (Li_1) and Foam Core, 662-lb 2-ft (Front (Li_2) and Backside Li_4) Tests)

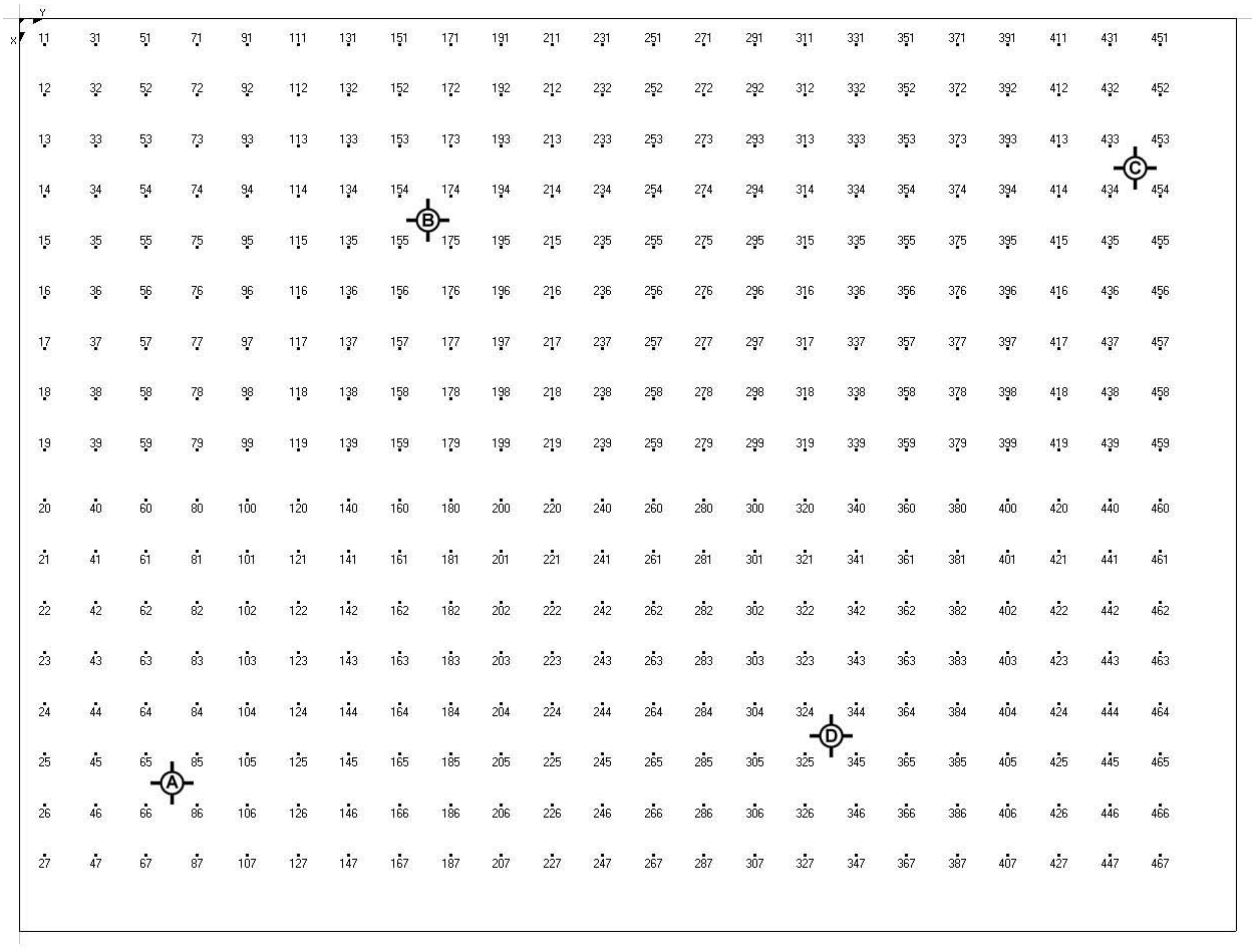

Figure 2. Test Mesh for the Webcore 662-lb 3-ft Panel (Li_3) Backside Test

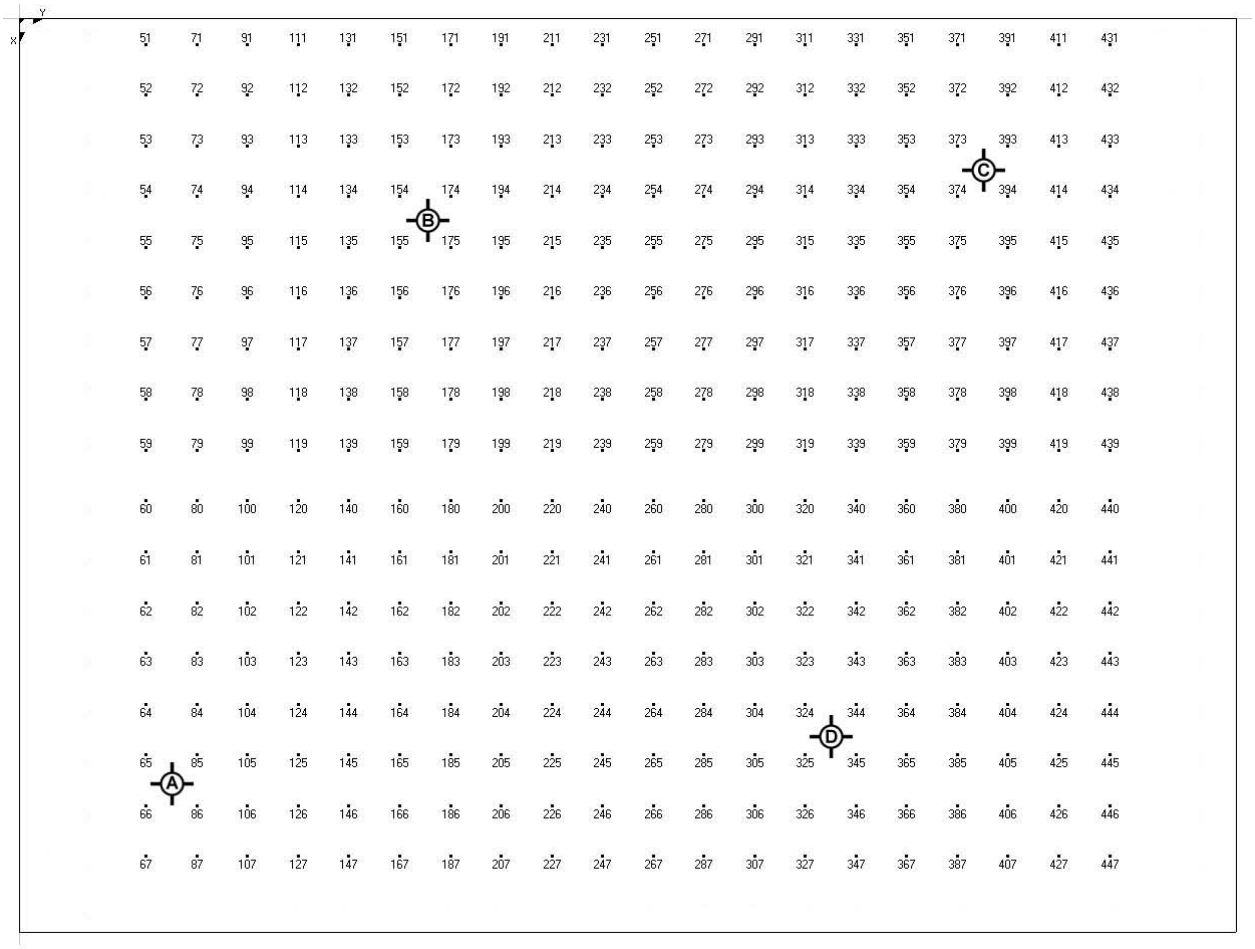

Figure 3. Test Mesh for the Undamaged Webcore Panel (Li_5) with End Fixtures

Accelerometer Locations

Most SIDER tests use four accelerometers, arranged on an almost symmetrical pattern. However, the symmetry is deliberately broken so that the accelerometer locations are partly randomized. For these inspections, four accelerometers were used for the SIDER calculations, each with a nominal sensitivity of 100 mV/g. For the test of the undamaged Webcore panel, accelerometer C had to be relocated because the steel end fixtures covered a part of the panel where the accelerometer was to be placed. The accelerometer details are shown in Table 2. The test mesh figures 1-3 also show the accelerometer positions as symbols.

Table 2. Location of the Accelerometers

Accelerometer	S/N	Sensitivity	Analyzer channel	X	Y	Z
A	56034	102.8 mV/g	2	30”	6”	0”
B	73280	101.9 mV/g	3	8”	16”	0”
C (all tests except Li_5)	48917	102.0 mV/g	4	6”	44”	0”
C (test Li_5)	48917	102.0 mV/g	4	6”	38”	0”
D	73282	101.8 mV/g	5	28”	32”	0”

Data Quality

On site, the data quality was primarily assessed by observation of the individual coherence functions for each accelerometer. When the coherence was atypically poor, the measurement was repeated until either the coherence improved, or it was assessed that the low coherence was a structural issue rather than a test issue. After the fact, the data quality is assessed by determining the average coherence for each accelerometer. Figure 4 compares the total average coherence for each panel. In keeping with the standard procedures instituted for the SIDER testing, the average coherence is shown separately for each transducer and panel in Figure 5 through Figure 9. In this way, instrumentation or local structural problems can sometimes be identified.

Note that all Coherence axes are expanded, and only show the range 80-100%. We would normally consider a high quality data set to have an average coherence in excess of 90%, and preferably more than 95%.

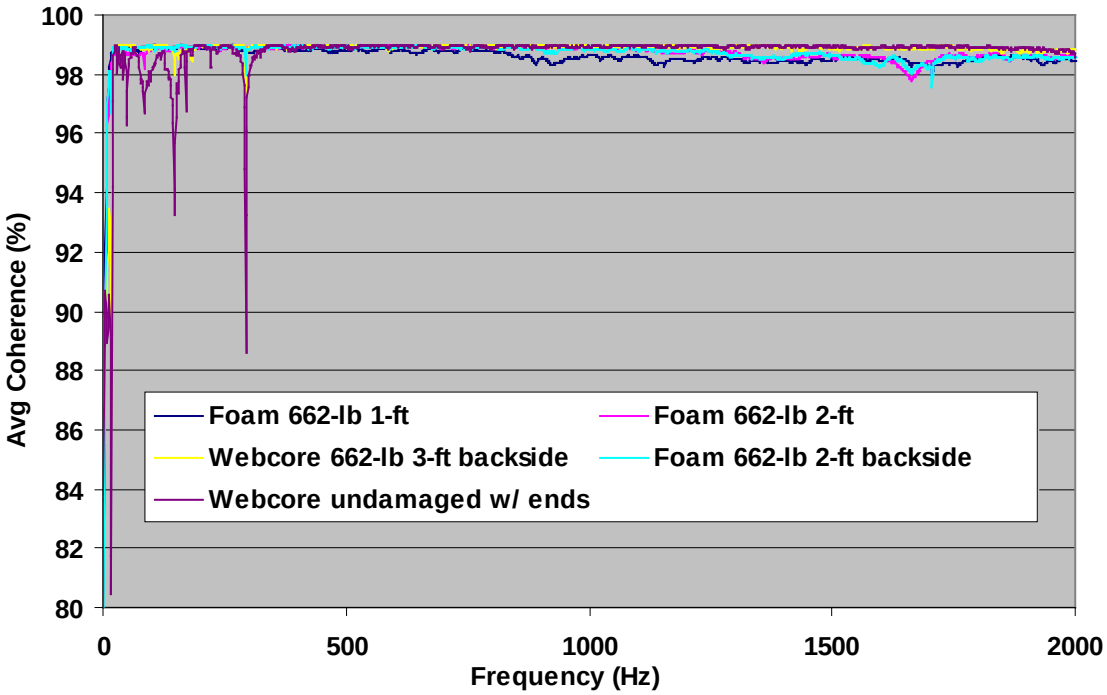

Figure 4. Average Coherence Comparison between Test Parts

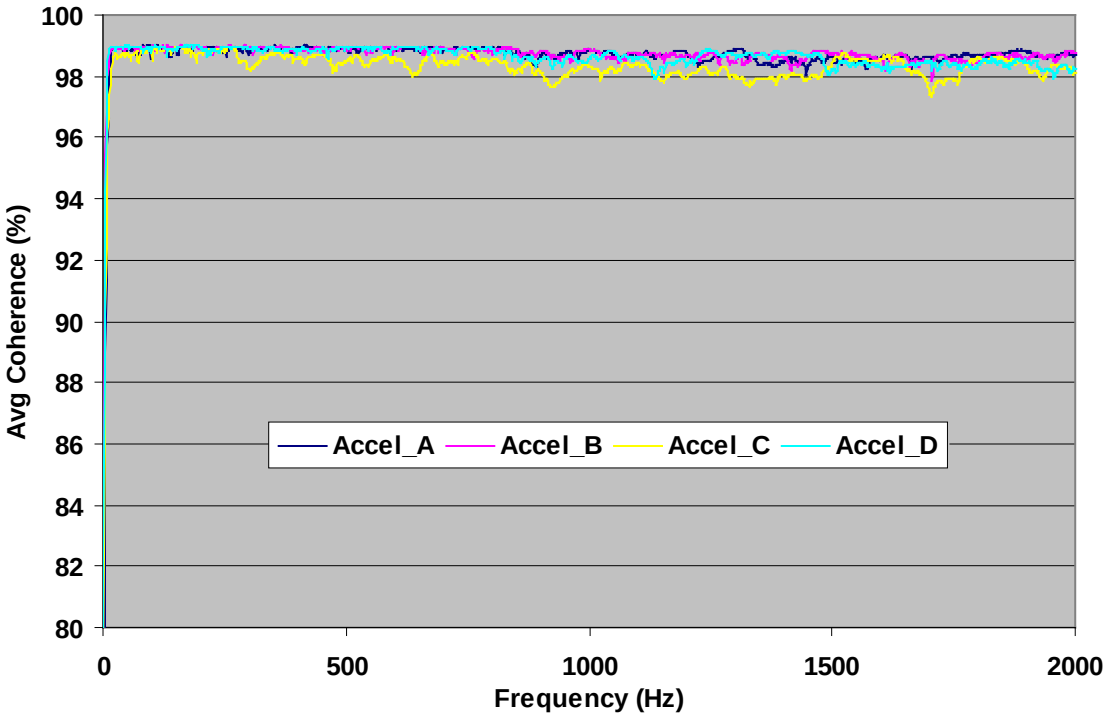

Figure 5. Average Coherence by Accelerometer for Foam Core 662-lb 1-ft

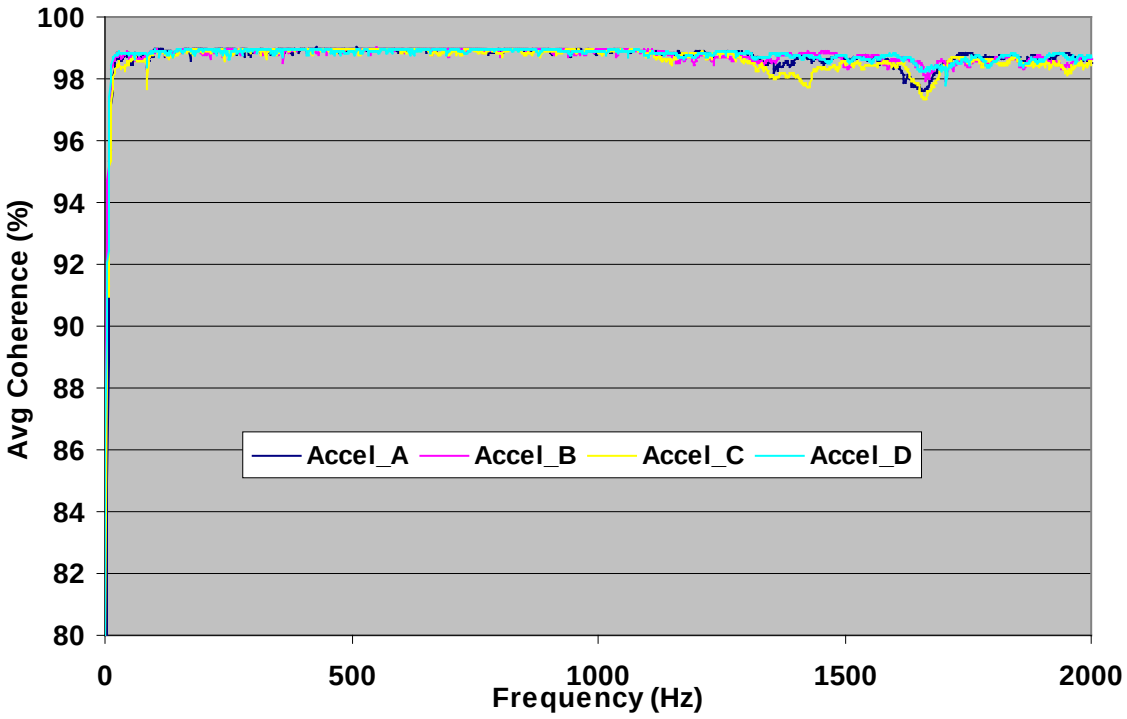

Figure 6. Average Coherence by Accelerometer for Foam Core 662-lb 2-ft

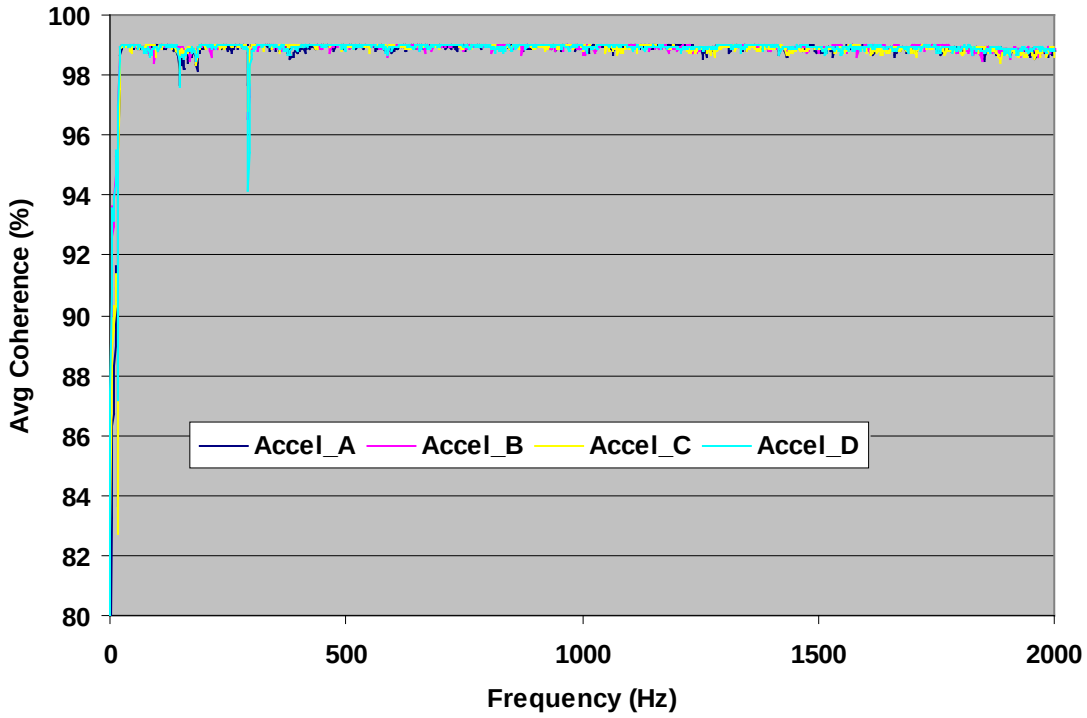

Figure 7. Average Coherence by Accelerometer for Webcore 662-lb 3-ft Backside Test Average Coherence by Accelerometer for Webcore 662-lb 3-ft Backside Test

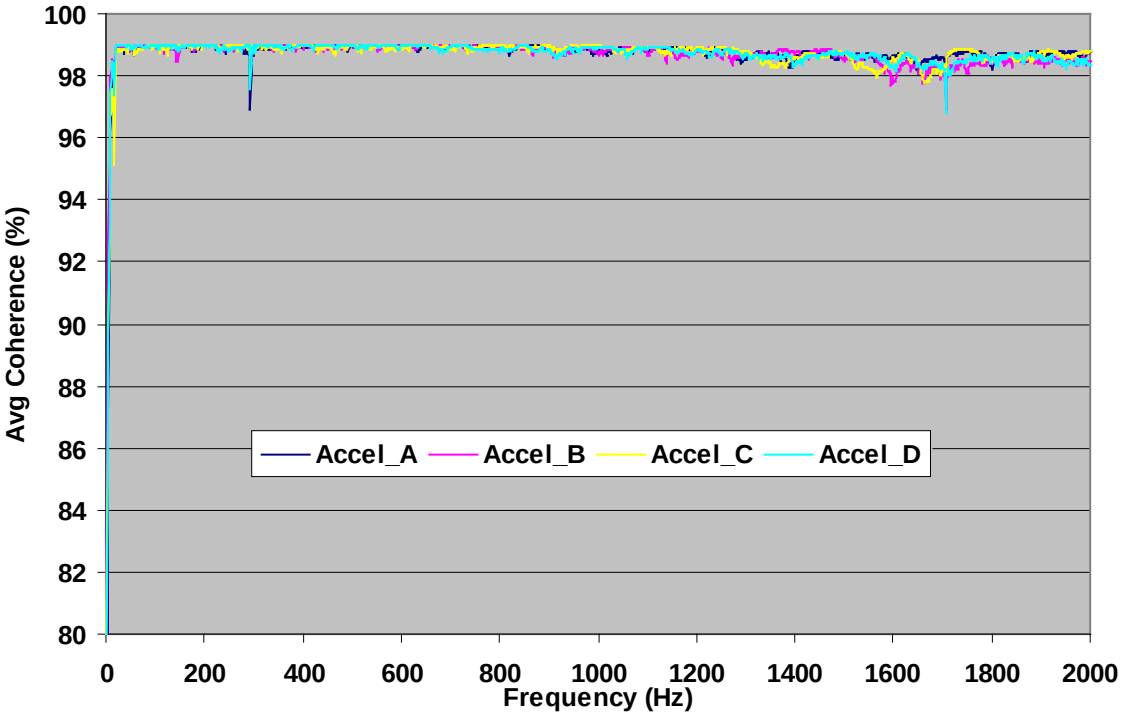

Figure 8. Average Coherence by Accelerometer for Foam Core 662-lb 2-ft Backside Test

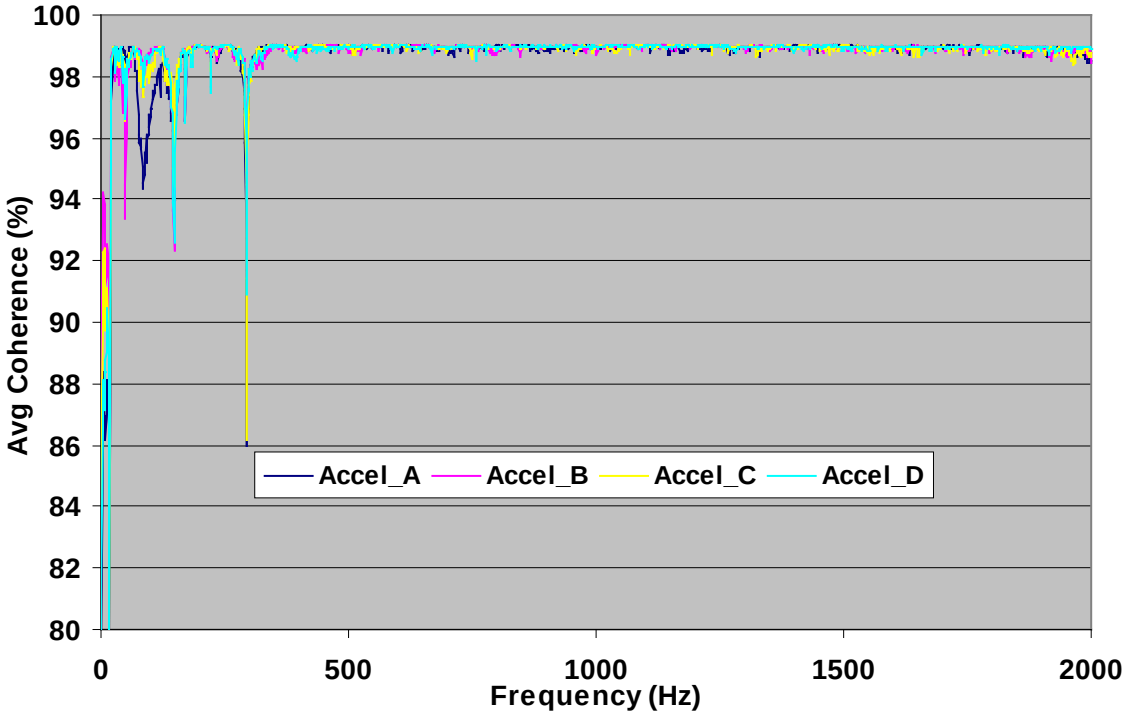

Figure 9. Average Coherence by Accelerometer for Webcore Undamaged with End Fixtures

Observations from the Average Coherence Results

For all panels and all accelerometers the data have a very good quality in the range of about 200 Hz to 1200 Hz, although all data are acceptable for SIDER analysis up to the maximum recorded frequency of 2 kHz.

Data below 200 Hz are more variable, though still of good quality. This slight degradation is typical for resonant structures and is not of concern for the SIDER analysis that typically uses higher frequency data.

Based on these results, it was decide to conduct all the SIDER analyses using data from the frequency range 200 Hz to 1200 Hz.

Sider Test Results

Typically, SIDER is used as a preliminary test method for rapidly interrogating large structures. If structures or components to be inspected are small, that is, a few square feet, then conventional NDE methods such as ultrasonic testing may be more appropriate. The SIDER results for these panels are therefore presented recognizing that SIDER is probably not the optimum test for these small panels.

The SIDER results can be used in a number of ways. First, an evaluation of the part quality can be determined from a single one-off inspection. Here, variations in stiffness in the structure can be identified. This is similar to what is being done for this specific effort. When multiple nominally identical components of the same configuration are manufactured, differences between them can be mapped to verify part-to-part uniformity. Once the structure is placed in service, a subsequent SIDER inspection can be used to identify areas that have a stiffness change which can occur either as a result of structural loading or in-service damage.

As described earlier, based on the coherence data, the SIDER analysis was conducted from 200 Hz to 1200 Hz, being the frequency range where the average coherence is above about 98%.

Figure 10 through Figure 29 show the SIDER contour plots for each of the panels. The axes numbering is the distance in inches from the global origin. The symbols identify the locations of the response transducers. There are four plots for each test. SIDER is a directional test, thus there is one plot for each of the two directional inspections (one for the analysis in the x-direction and one for the analysis in the y-direction). In addition, the data obtained for this series of tests were used to investigate a recent modification to the SIDER algorithm. For a normal SIDER analysis, all individual structural irregularity indices are equally weighted before they are combined to give the contour plot results. The modified SIDER algorithm uses a pie-plate weighting algorithm which reduces the emphasis of the results obtained near each accelerometer. For this analysis with a 2-inch rectangular mesh, a pie-plate weighting function with cutoff distances of 5.1 inches and 10.2 inches was used. The overall weightings were normalized to maintain the same relative significance of absolute SIDER numbers.

The contour graphs are all shown to the same scale, this being the maximum SIDER value observed in all the tests. The color bar at the side of each of the SIDER contour plots have the same scaling, such that the same contour color identifies similar SIDER values. White indicates little or no irregularity in structural stiffness, and red indicates a higher level of irregularity.

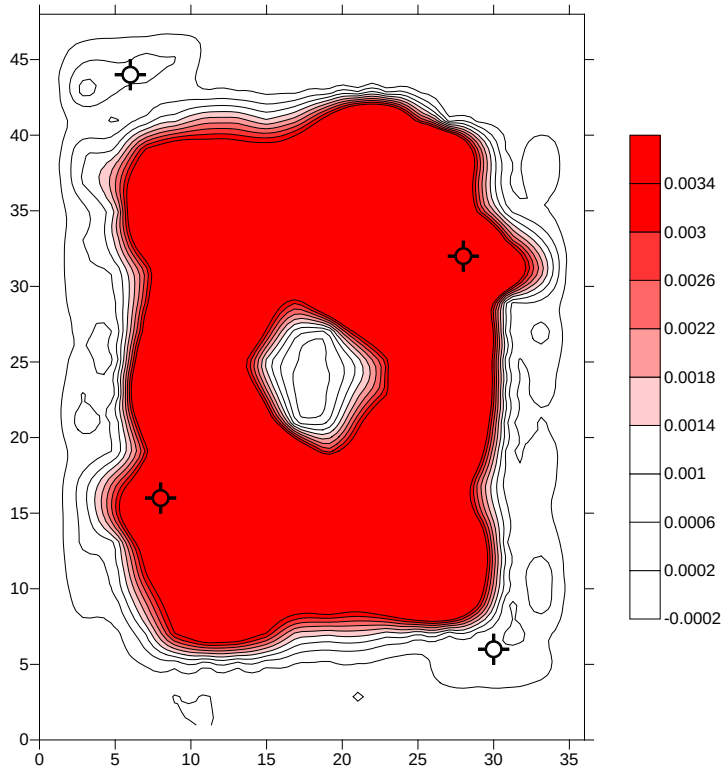

Figure 10. Foam 662-lb 1-ft (Li_1) X-Direction Analysis -Unweighted

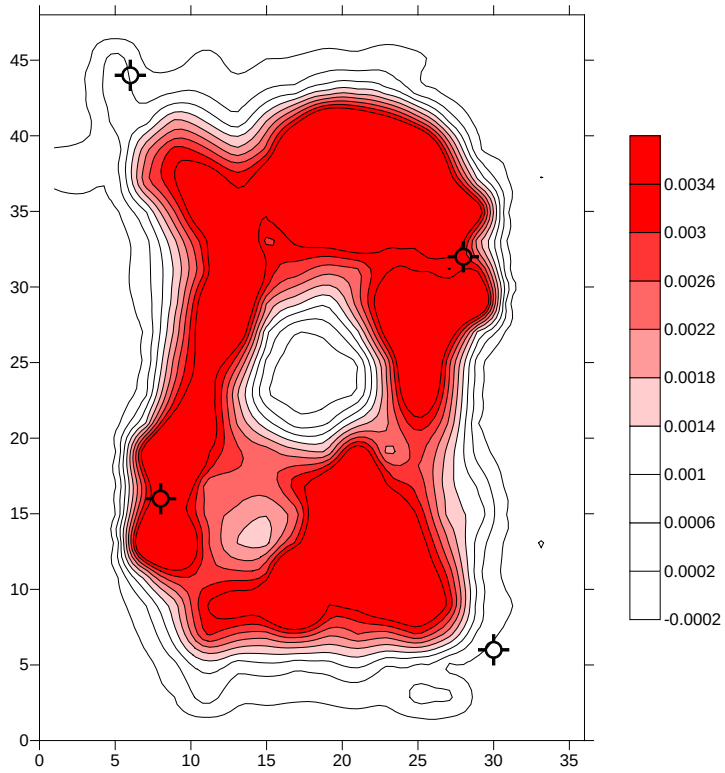

Figure 11. Foam 662-lb 1-ft (Li_1) Y-Direction Analysis -Unweighted

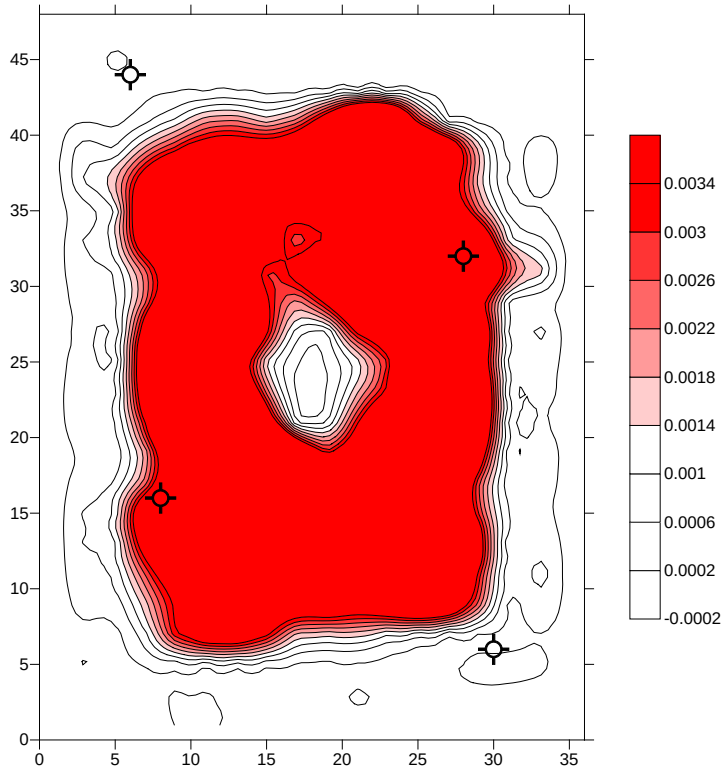

Figure 12. Foam 662-lb 1-ft (Li_1) X-Direction Analysis -Pie-Plate Weighting

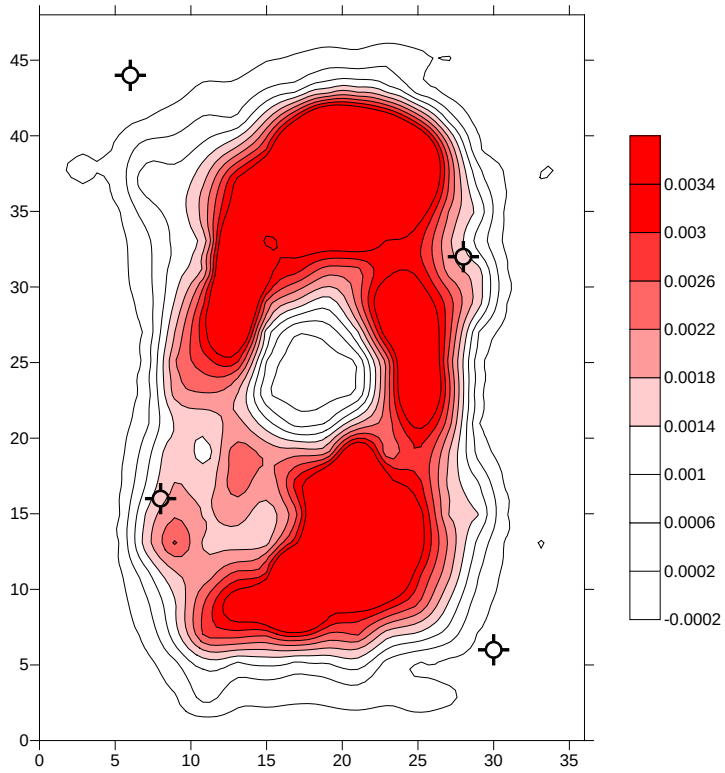

Figure 13. Foam 662-lb 1-ft (Li_1) Y-Direction Analysis -Pie-Plate Weighting

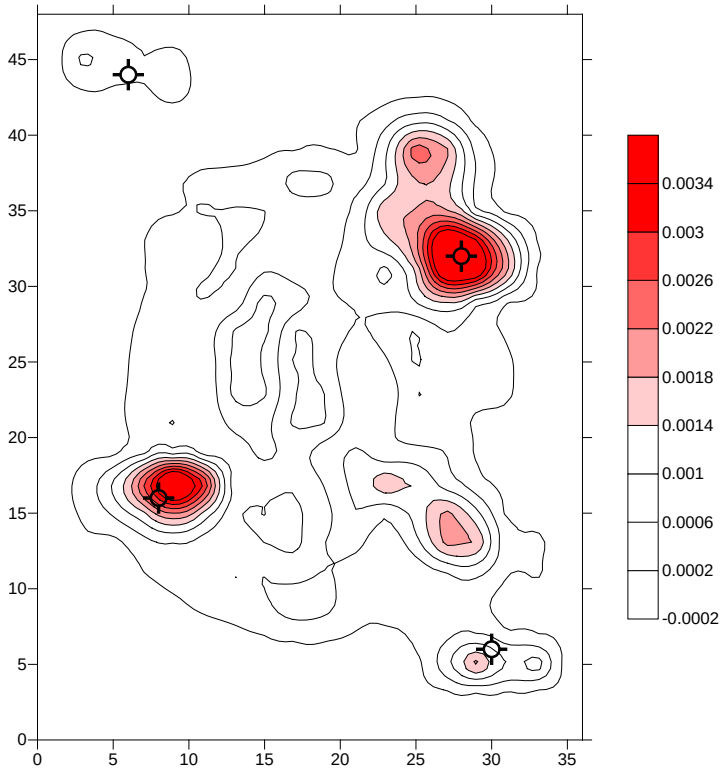

Figure 14. Foam 662-lb 2-ft (Li_2) X-Direction Analysis -Unweighted

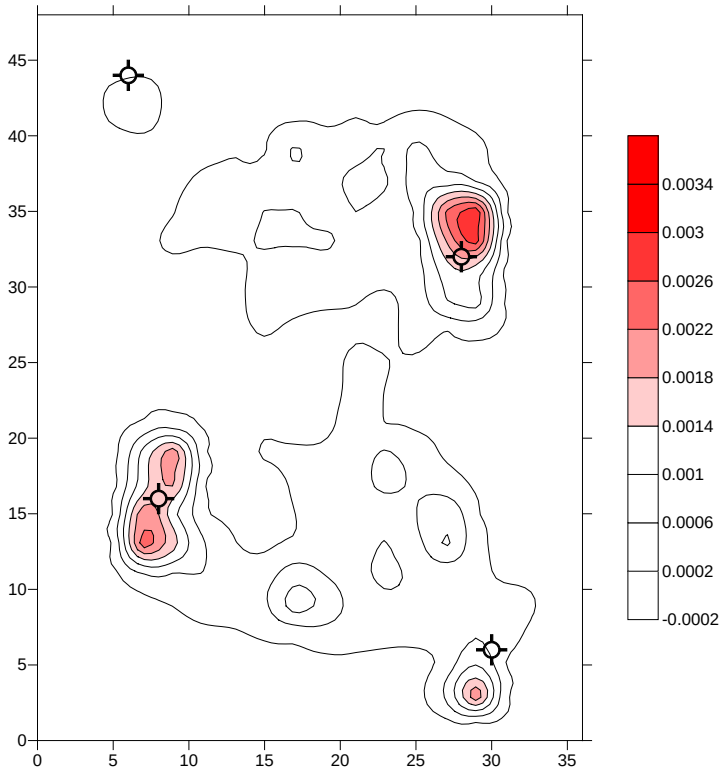

Figure 15. Foam 662-lb 2-ft (Li_2) Y-Direction Analysis -Unweighted

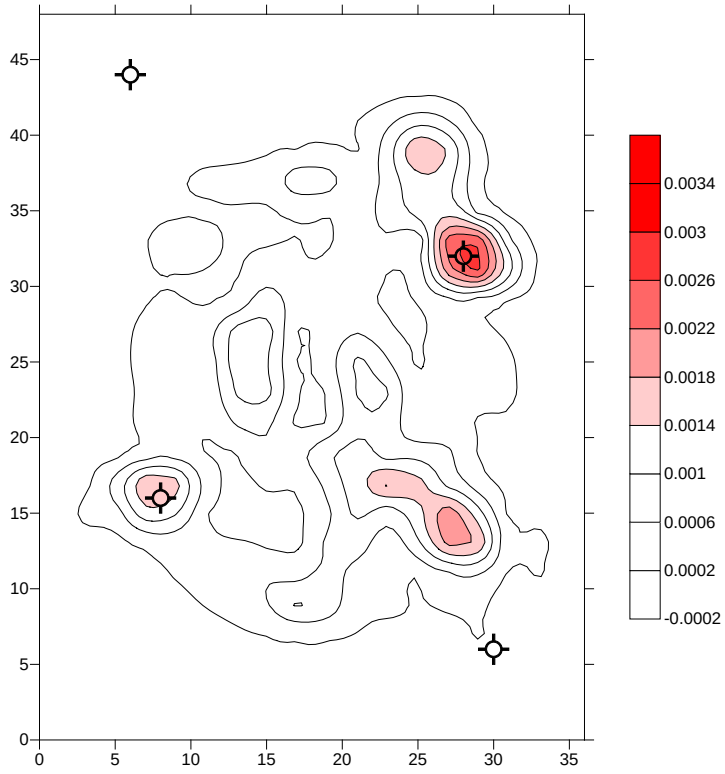

Figure 16. Foam 662-lb 2-ft (Li_2) X-Direction Analysis -Pie-Plate Weighting

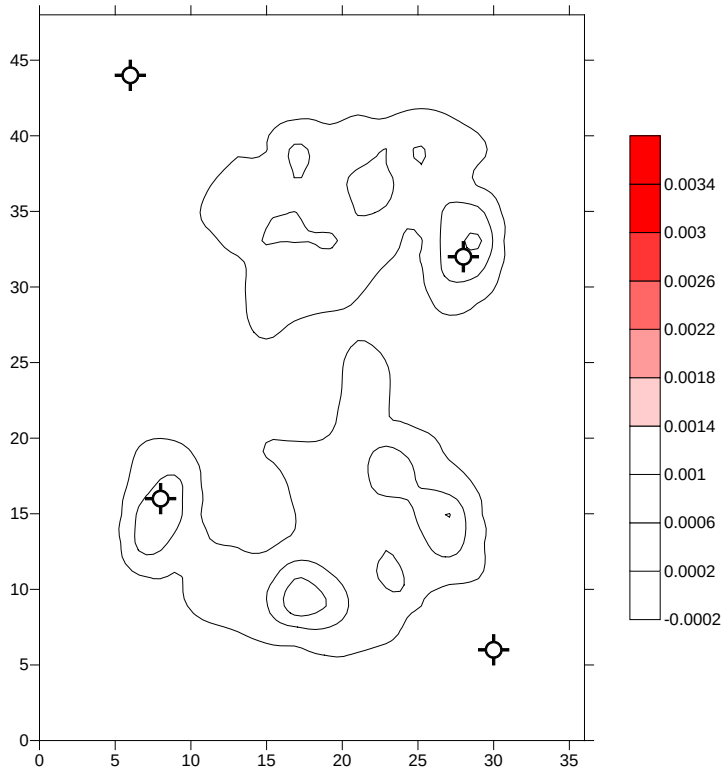

Figure 17. Foam 662-lb 2-ft (Li_2) Y-Direction Analysis -Pie-Plate Weighting

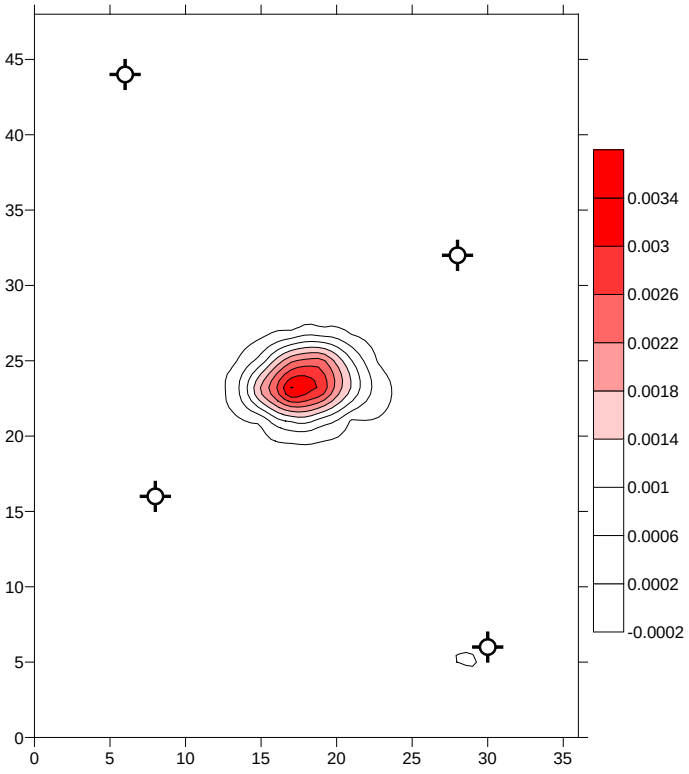

Figure 18. Webcore 662-lb 3-ft (Li_3) X-Direction Analysis – Unweighted – Backside Test

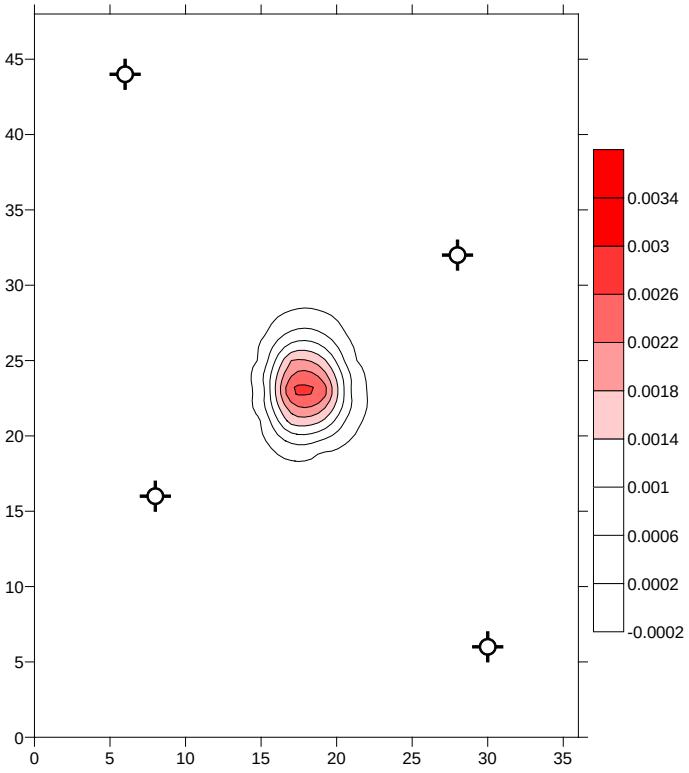

Figure 19. Webcore 662-lb 3-ft (Li_3) Y-Direction Analysis - Unweighted – Backside Test

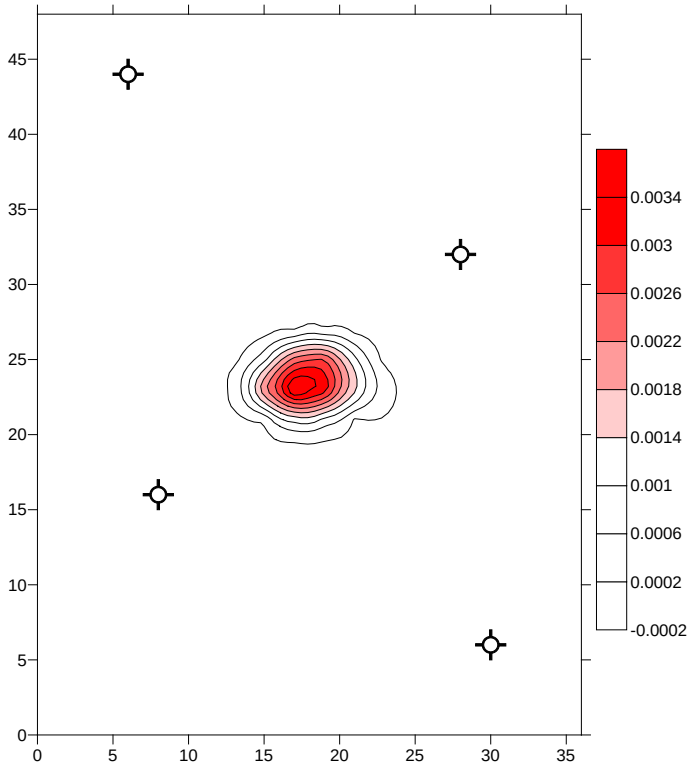

Figure 20. Webcore 662-lb 3-ft (Li_3) X-Direction Analysis - Pie-Plate Weighting – Backside Test

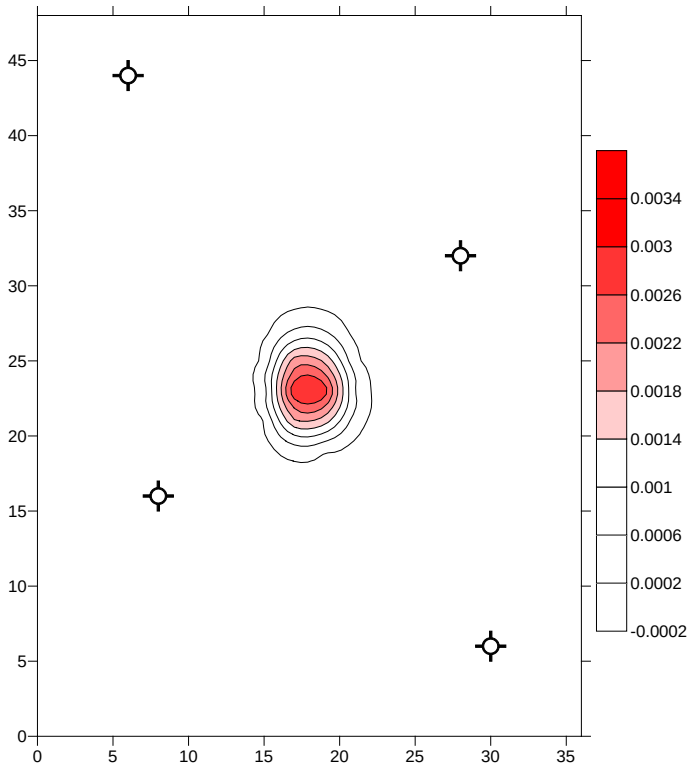

Figure 21. Webcore 662-lb 3-ft (Li_3) y-Direction Analysis -Pie-Plate Weighting – Backside Test

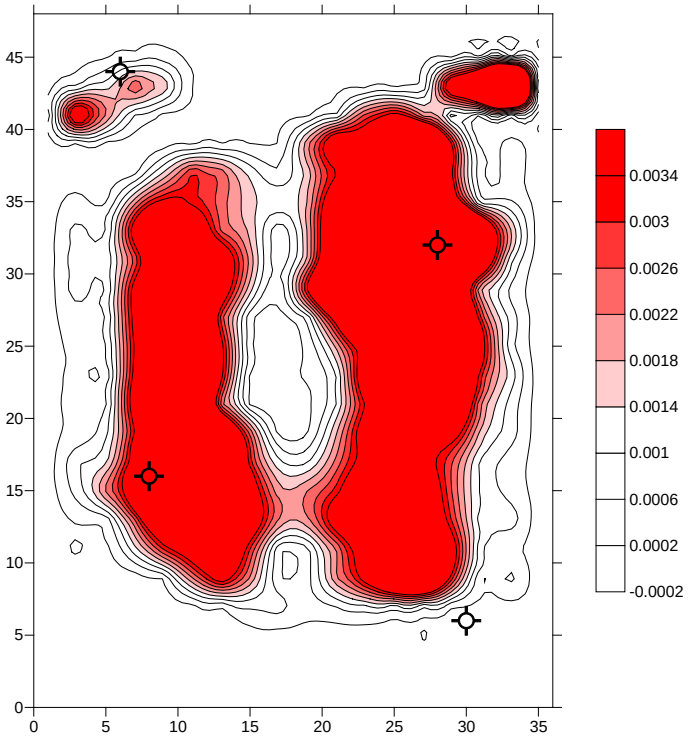

Figure 22. Foam 662-lb 2-ft (Li_4) x-Direction Analysis – Unweighted – Backside Test

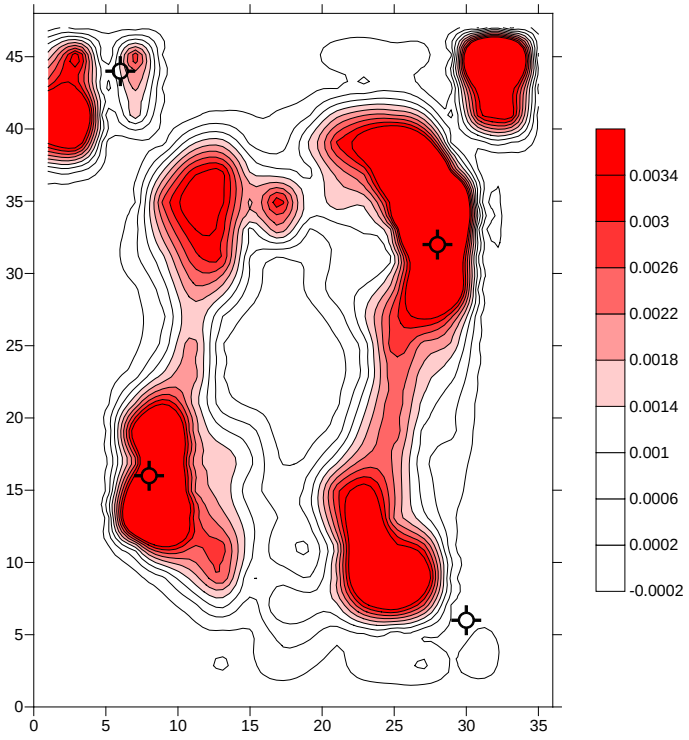

Figure 23. Foam 662-lb 2-ft (Li_4) Y-Direction Analysis – Unweighted – Backside Test

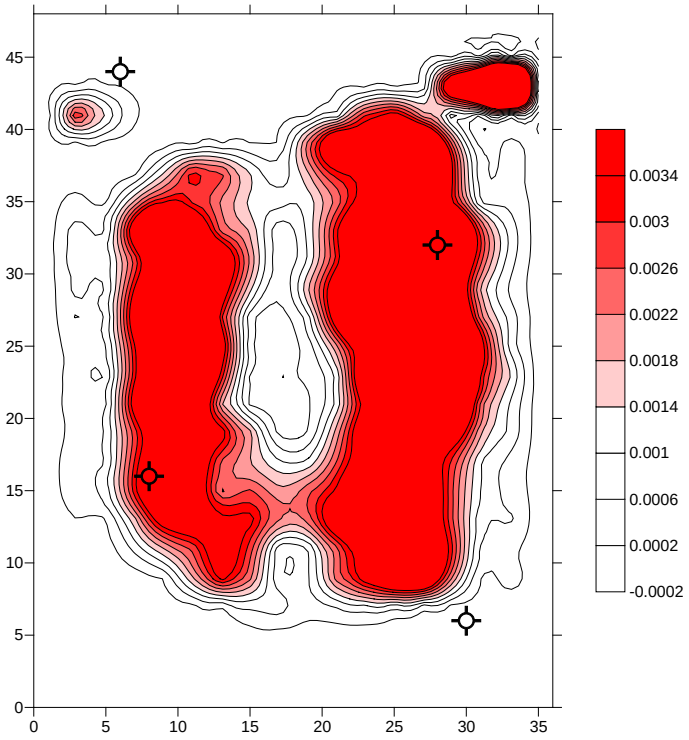

Figure 24. Foam 662-lb 2-ft (Li_4) x-Direction Analysis -Pie-Plate Weighting – Backside Test

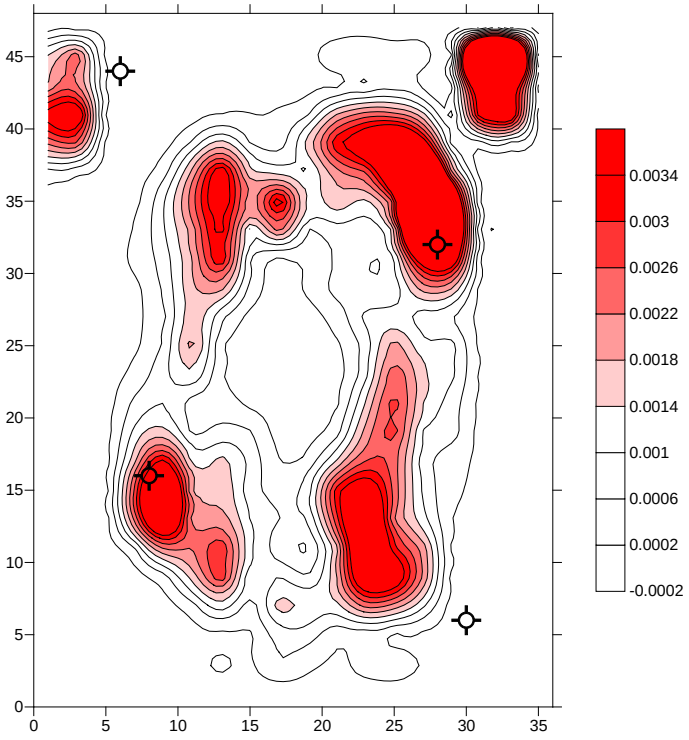

Figure 25. Foam 662-lb 2-ft (Li_4) y-Direction Analysis -Pie-Plate Weighting – Backside Test

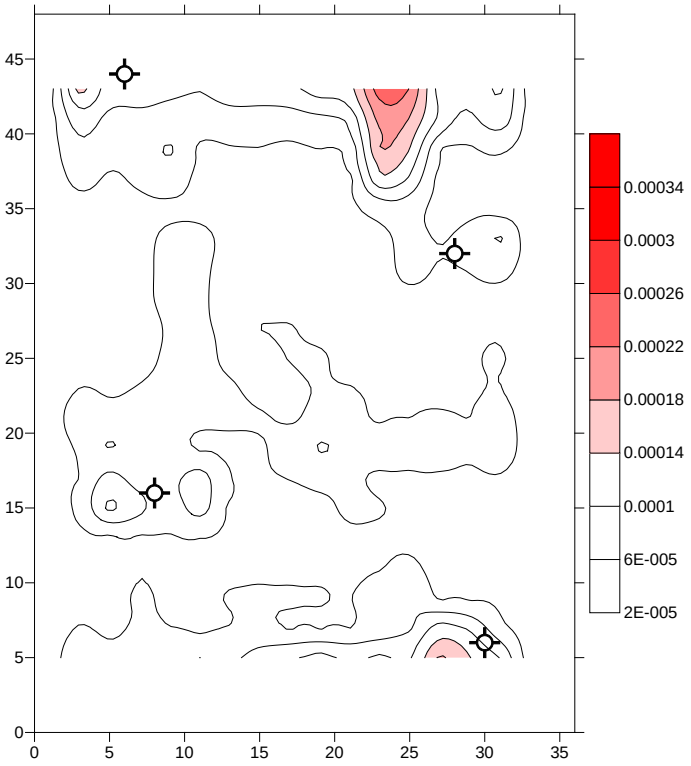

Figure 26. Webcore Undamaged (Li_5) x-Direction Analysis – Unweighted 10 × Magnification

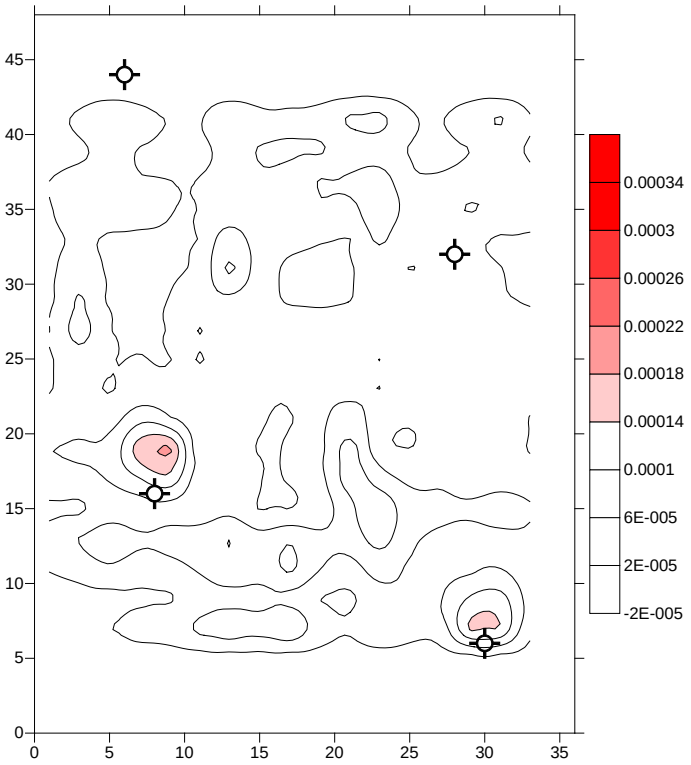

Figure 27. Webcore Undamaged (Li_5) y-Direction Analysis – Unweighted 10 × Magnification

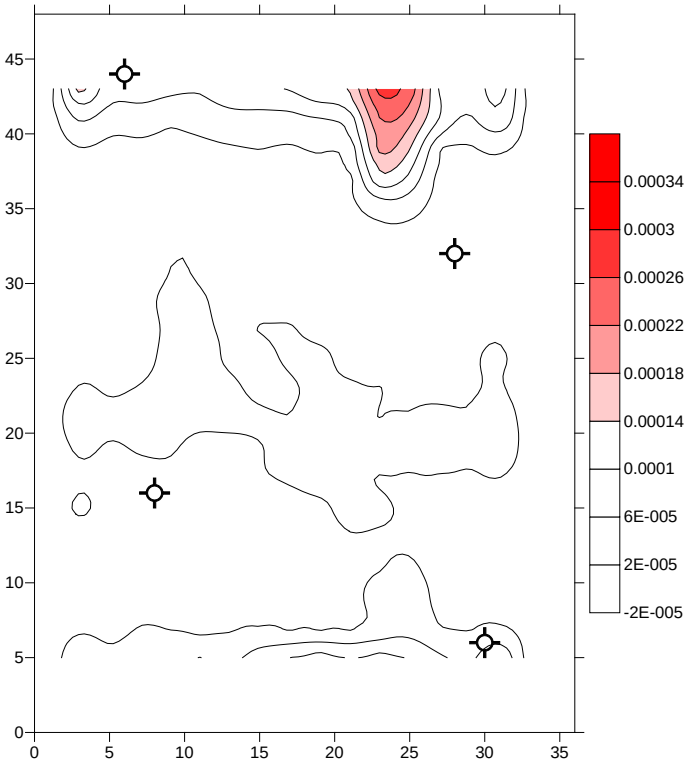

Figure 28. Webcore Undamaged (Li_5) x-Direction Analysis -Pie-Plate Weighting 10 × Magnification

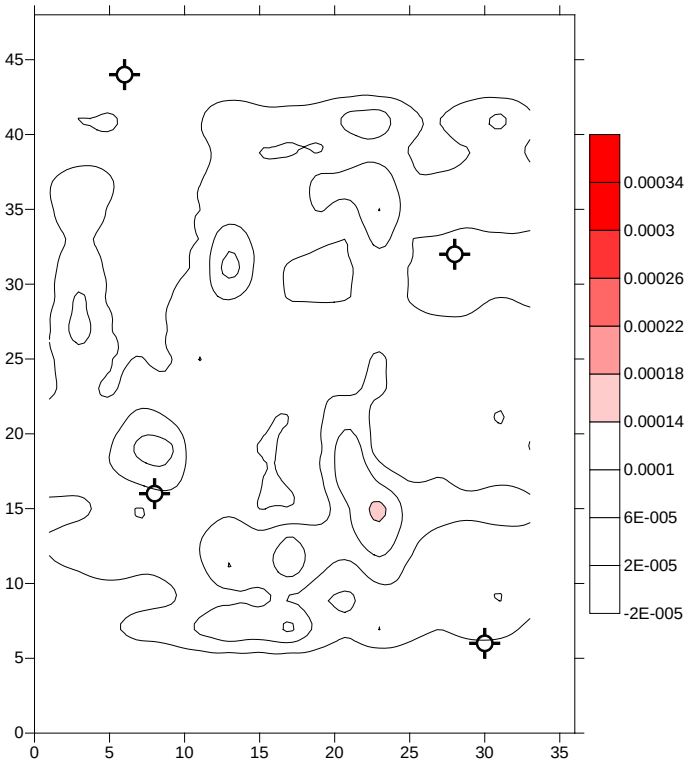

Figure 29. Webcore Undamaged (Li_5) y-Direction Analysis -Pie-Plate Weighting 10 × Magnification

Conclusions

The SIDER test results from two Webcore panels are discussed first. The panel that had not been tested, L_5, showed a uniform SIDER value over most of the panel with only minor indications near the end fixtures. This shows that the panel was manufactured with a consistent quality. For impacted Webcore panel, L_3, the only indication of structural variation is in the center of the panel, where it was impacted with the drop weight. This is consistent with prior SIDER testing on Webcore impacted panels. The damage has been shown to be highly localized and of a minimal size.

The SIDER test results of the foam core panels is more complex. One consistent feature for each of these panels is that the location where the impact occurred did not indicate a stiffness variation. This is typical of foam core materials. Typically, the impact area does not see a large variation in spatial stiffness. Damage emanates a certain distance from the actual impact site. The other features indicated by SIDER are more confusing. The lower impact energy panel, L_1, shows a larger area of structural variation than panel L_2, which was impacted with twice the impact energy. It is not known if there was any difference in the way that the panels were impacted. There is the possibility that when panel L_1 was impacted, that the impactor was allowed to rebound and impact a second time since the height of the drop was only 1 foot. In any event, SIDER would indicate that there is a larger area of concern than for panel L_1 than for L_2.

The other comparison that needs addressing is the SIDER result from testing panel L_2 on the impact side and the side opposite the impact, indicated as Backside test in the figures. There is an obvious difference between the SIDER results from these two tests. Figure 22 through Figure 25 show a much larger area of structural variability than on the backside of the panel, which is shown in Figure 14 through Figure 17. This is not atypical since flexural deformation of composite sandwich structures often have more damage on the tensile surface than the compression surface. What is consistent, though, is that the areas of structural variability occur more along the y-axis of the panel than in the x-direction.

References

1. Ratcliffe, Colin P., Crane, Roger M, Gillespie, John W. Jr., “Damage Detection In Large Composite Structures Using A Broadband Vibration Method”, INSIGHT - Non-Destructive Testing and Condition Monitoring, *The Journal of The British Institute of Non-Destructive Testing*, January 2004.
2. Ratcliffe, Colin P., and Crane, Roger M., “A Non-Destructive Test Procedure for the Determination of the Structural Irregularity and Damage Evaluation Routine (SIDER) of Composite Structures”, Navy Case No. 83,356, August 2001.

NAVSEA
WARFARE CENTERS
Carderock Division